

# Astrobiology

Life on Earth (and elsewhere?)

Origins & distribution of habitable environments

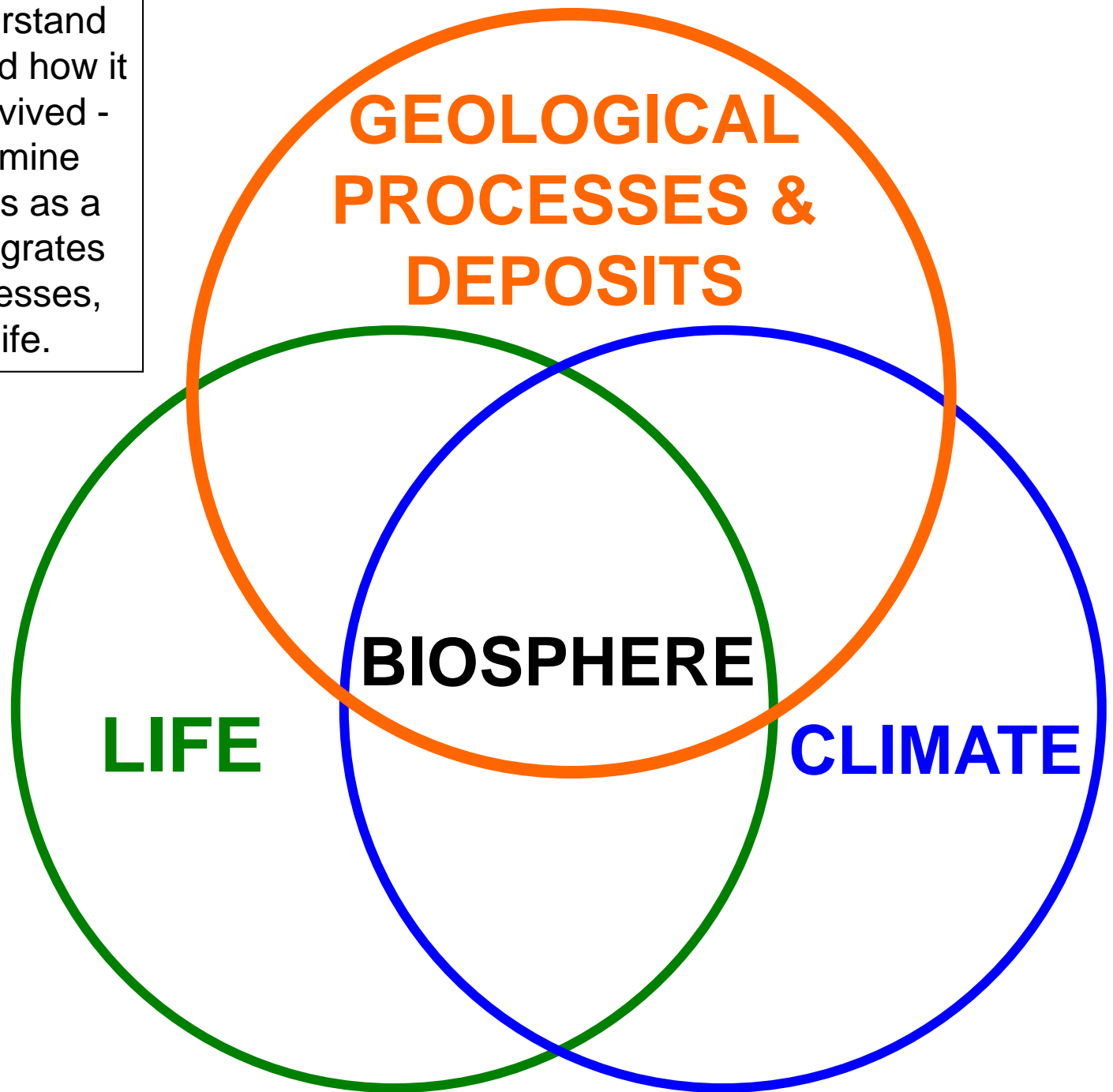
Origins of life

Long-term evolution of life & its environment

Distribution of life in the universe



In order to understand our biosphere and how it evolved and survived - we must determine how Earth works as a system that integrates geological processes, climate and life.

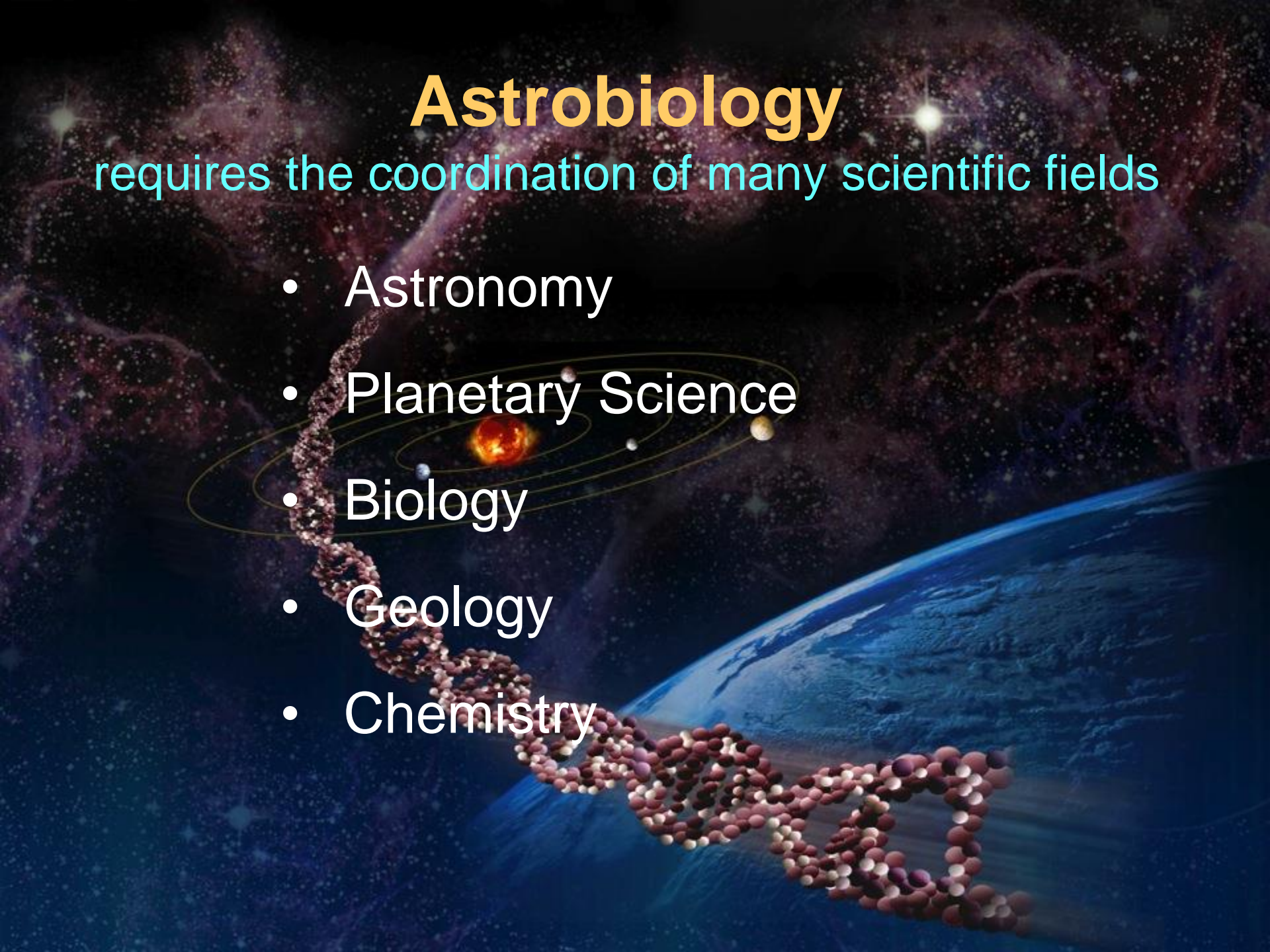




# Astrobiology

requires the coordination of many scientific fields

- Astronomy
- Planetary Science
- Biology
- Geology
- Chemistry





# NASA Astrobiology - Major Themes



**Origins & distribution of habitable environments:  
Earth**

Origins of life

Long-term evolution of life & its environment

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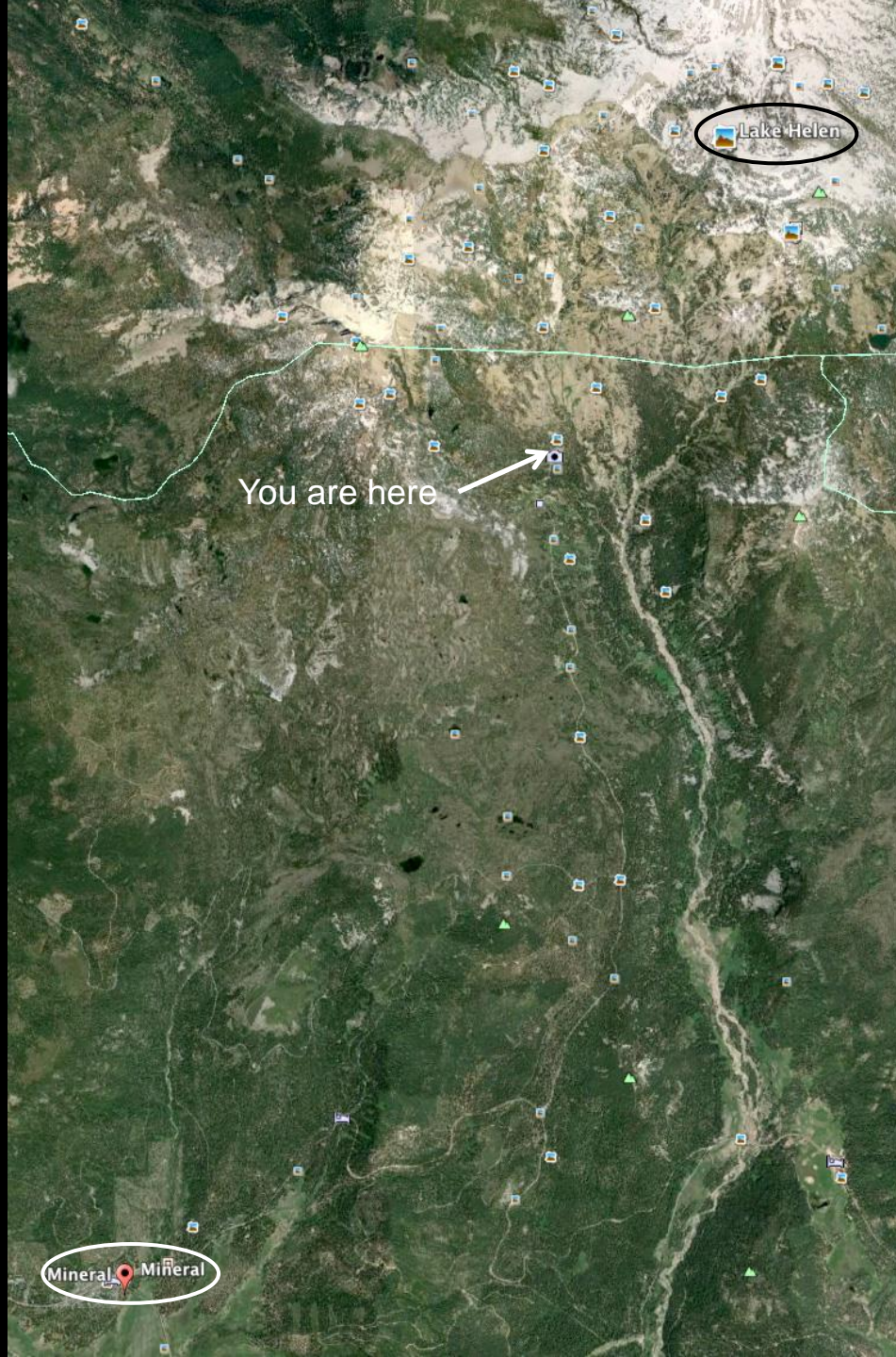
cineIIIotion



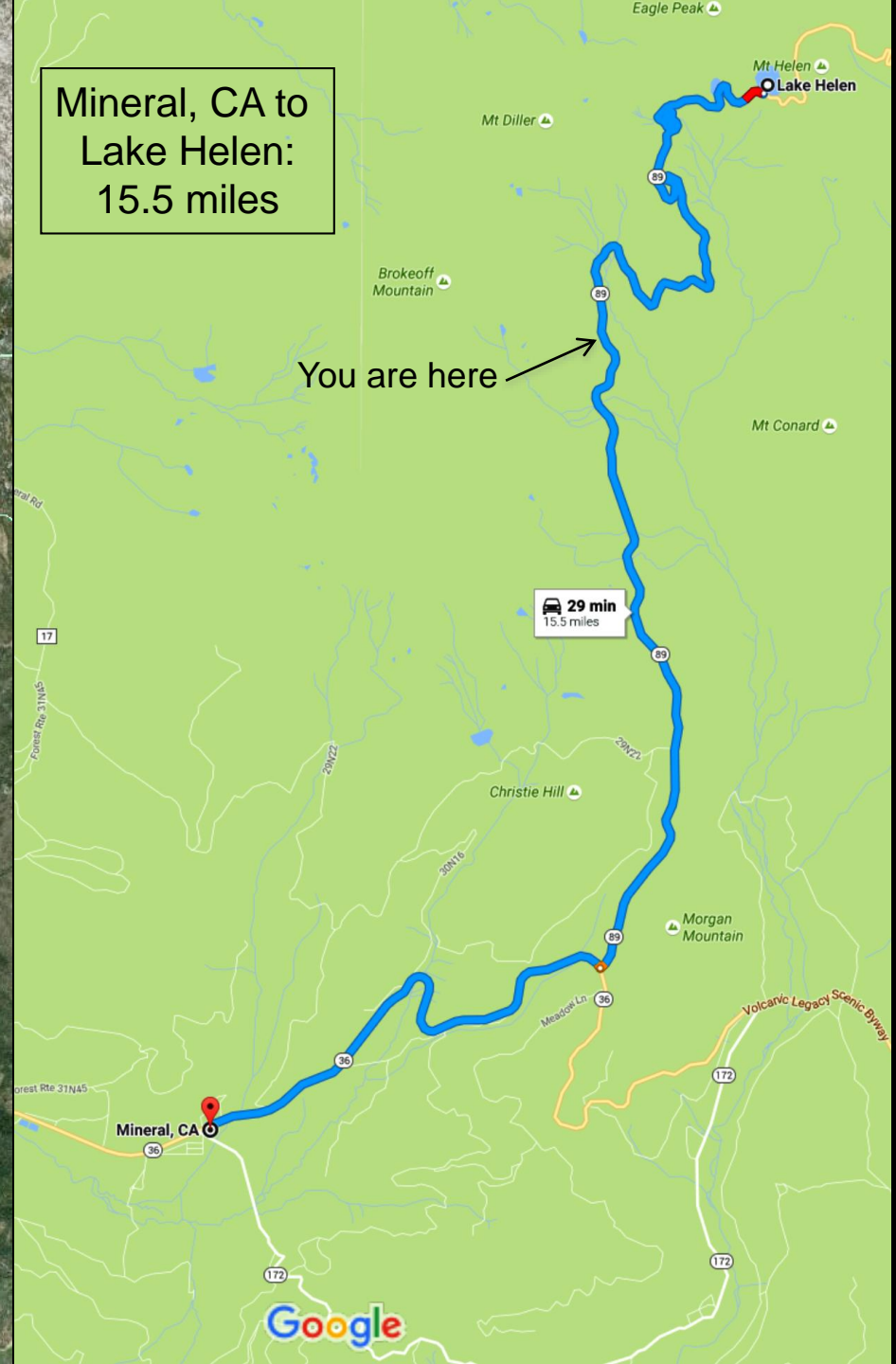








Mineral, CA to  
Lake Helen:  
15.5 miles



# Our everyday world lies entirely within a VERY thin layer

Masses:

Earth =  $6 \times 10^{24}$  kg

Oceans =  $1.4 \times 10^{21}$  kg

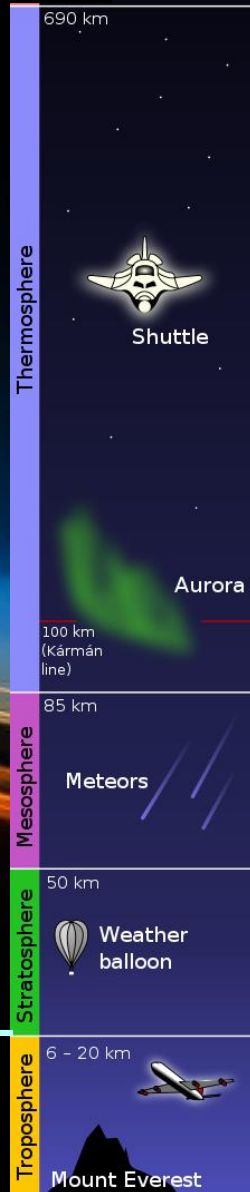
Atmosphere =  $3 \times 10^{18}$  kg

( Scale height [e=2.718] of Earth's atm. = 8.5 km or ~5.1 mi )

13 miles (~20 km)



> 80 - 90 % of  
atmosphere's mass





# Earth's crust and an apple's skin



Radius: ~6371 km (3959 miles)  
Crust: mostly 10 to 50 km (6 to 30 miles)  
Crust / Radius = 0.0016 to 0.0071



Radius: 40 mm  
Skin: 0.1 mm  
Skin / Radius = 0.0025

Processes occurring above and below our everyday world  
have shaped our biosphere in VERY important ways.



# Earth Rise 1968



This image revealed how finite our everyday environment is and that we must understand the important processes that sustain habitable planetary environments.



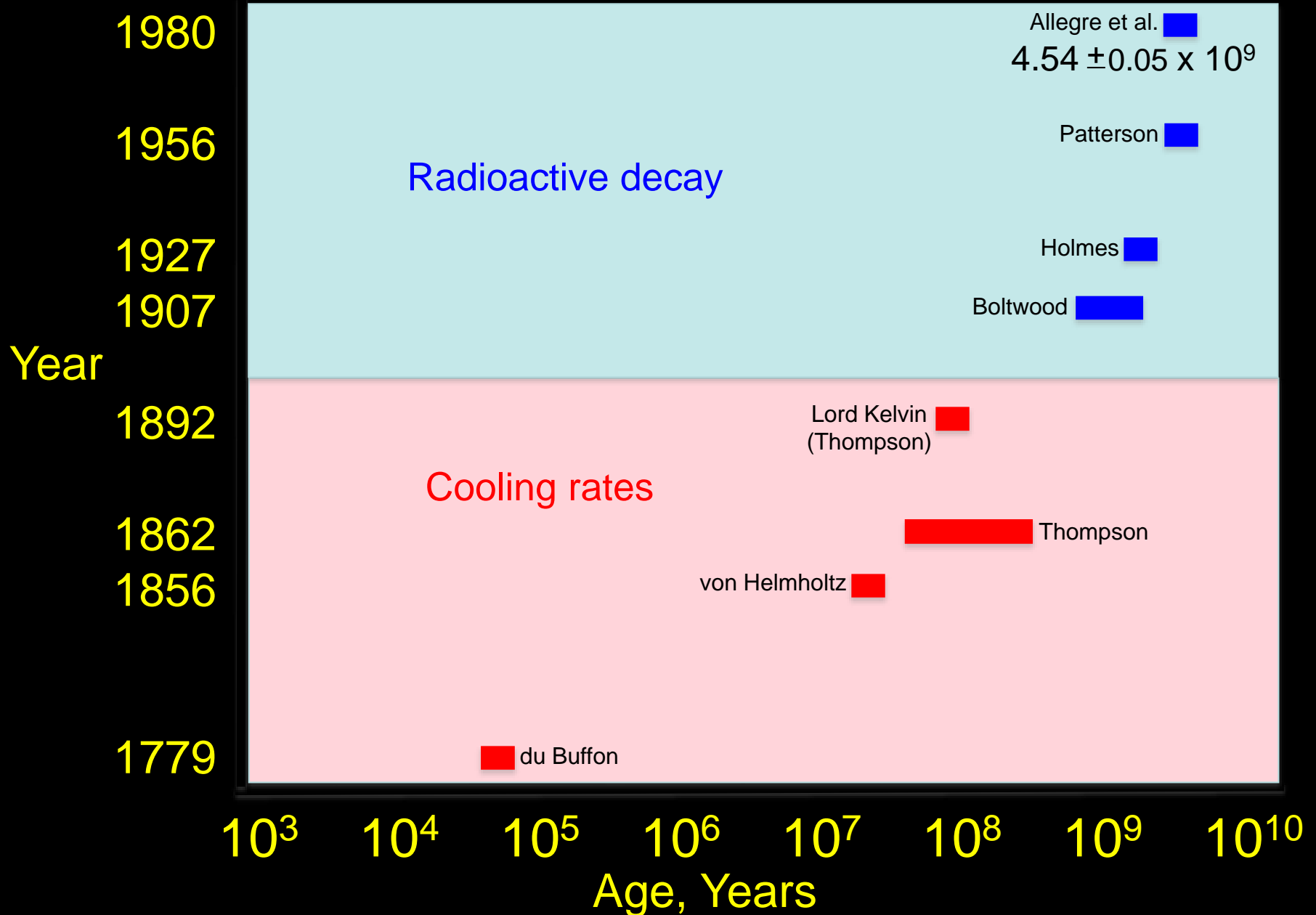


**Evidence of changing planetary environments has been recorded in layers of rocks**

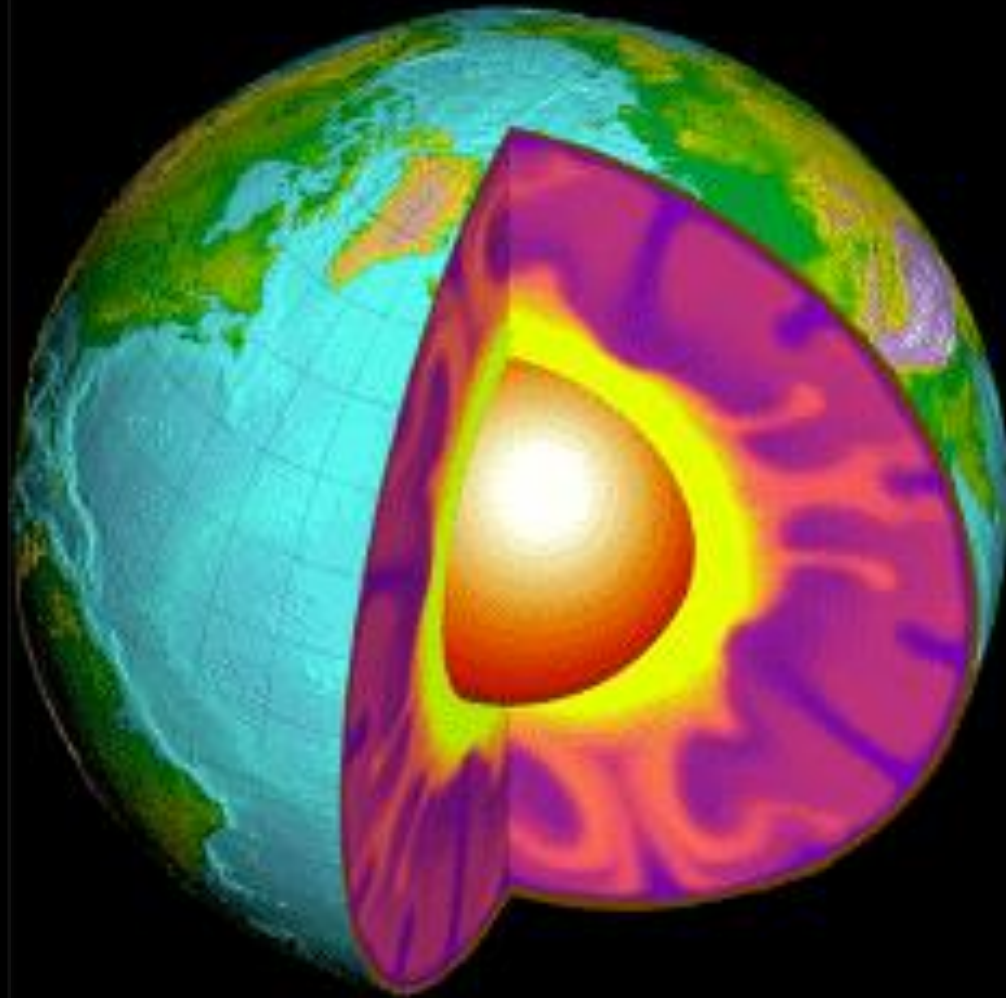
Toroweap overlook, Grand Canyon, AZ



# Determination of Earth's Age vs Year of Calculation



The decay of radioactive elements  
has made Earth's mantle and core very hot.

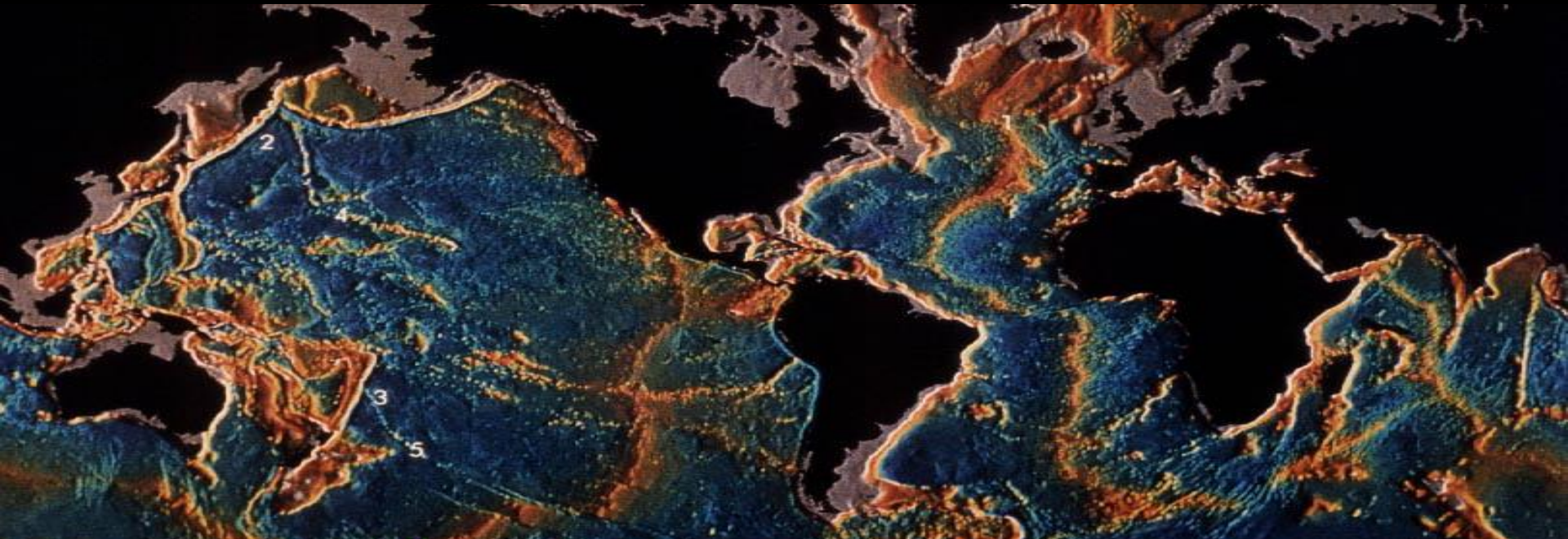


As heat escapes upward through the mantle and crust, thermal convection in the mantle causes sections of crust (the “plates”) to move around.





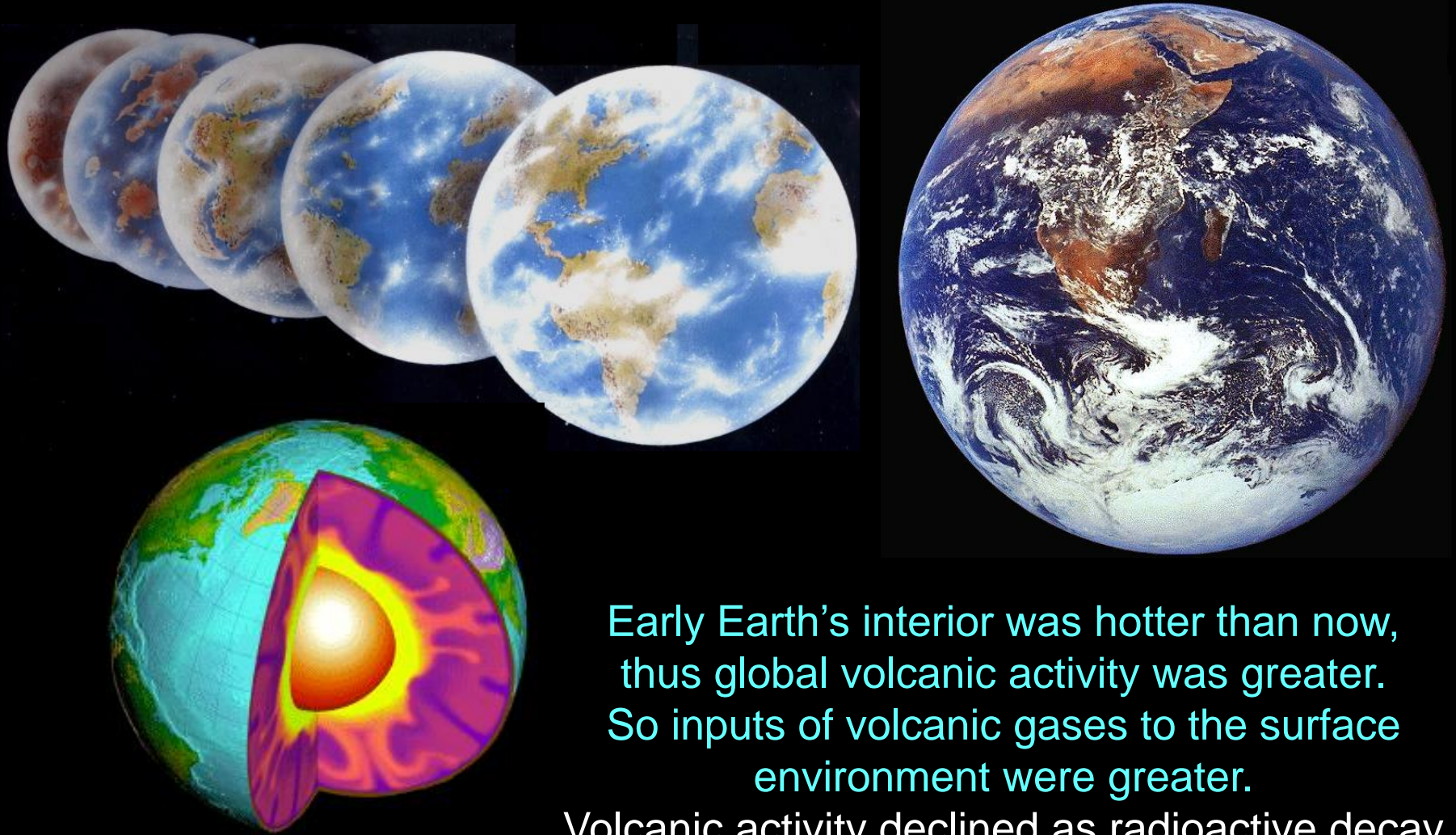
Layers of sedimentary rocks documented how volcanism changed global geography...



Ocean basins are volcanic plains. Volcanism moved the plains & continents horizontally.



# Long-term evolution of planets & surface environments



Early Earth's interior was hotter than now,  
thus global volcanic activity was greater.  
So inputs of volcanic gases to the surface  
environment were greater.

Volcanic activity declined as radioactive decay  
decreased the abundances of key radioisotopes.



3500 million years ago... Volcanic activity was much greater



3.5 billion years ago  
Smithsonian Institution mural

Volcanism provided nutrients and energy for life and also warmed the climate



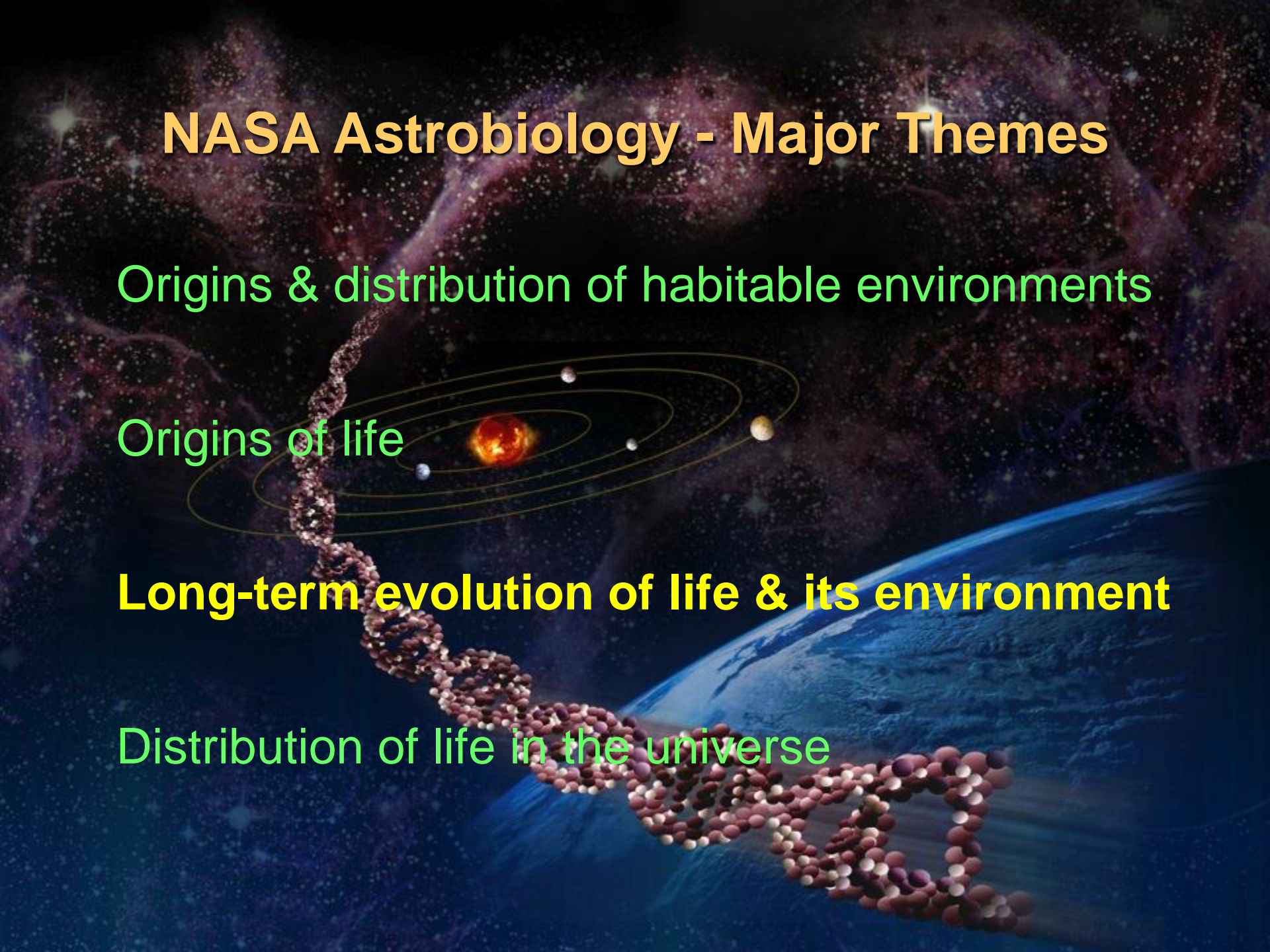
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# Understanding life in its planetary and cosmic context

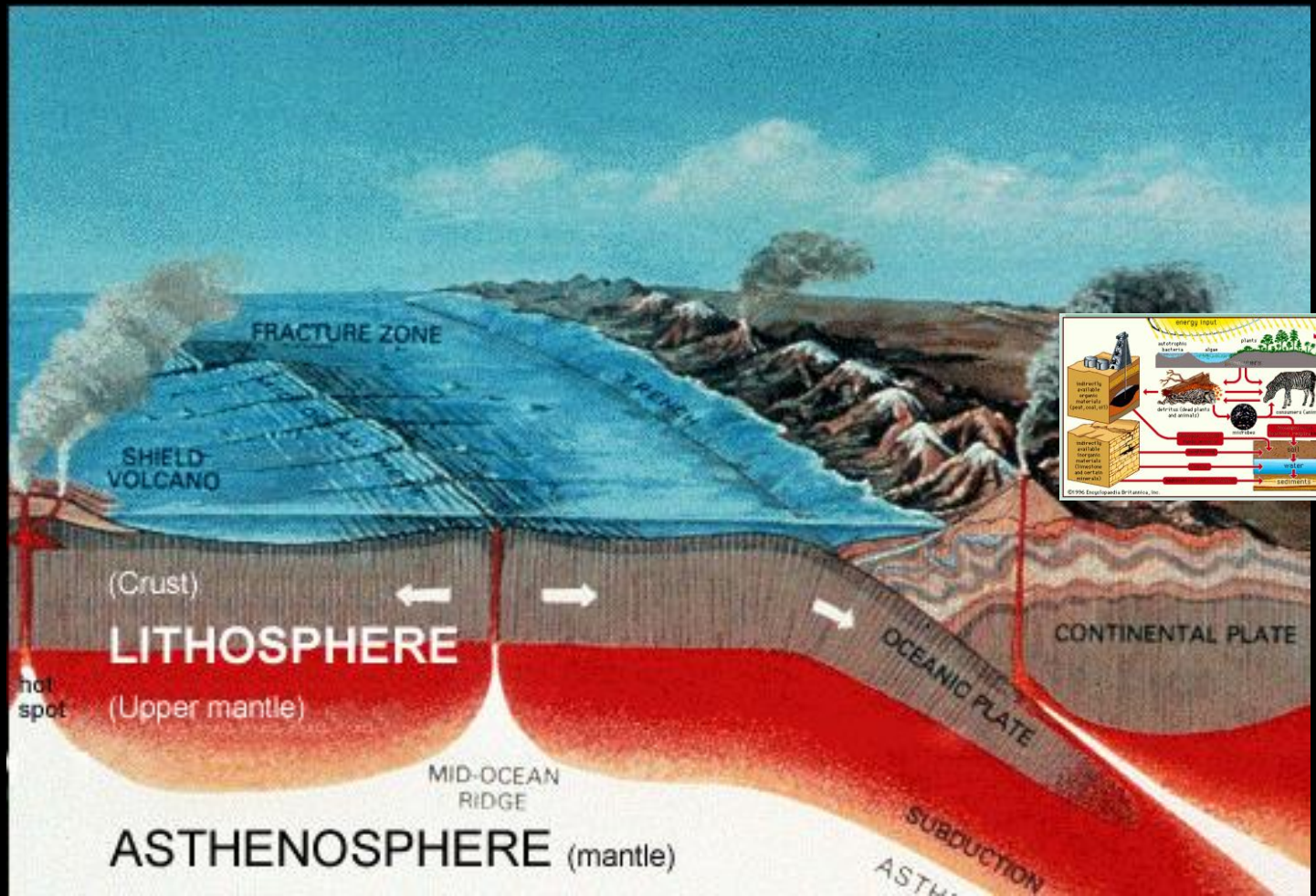
Space



Atmosphere

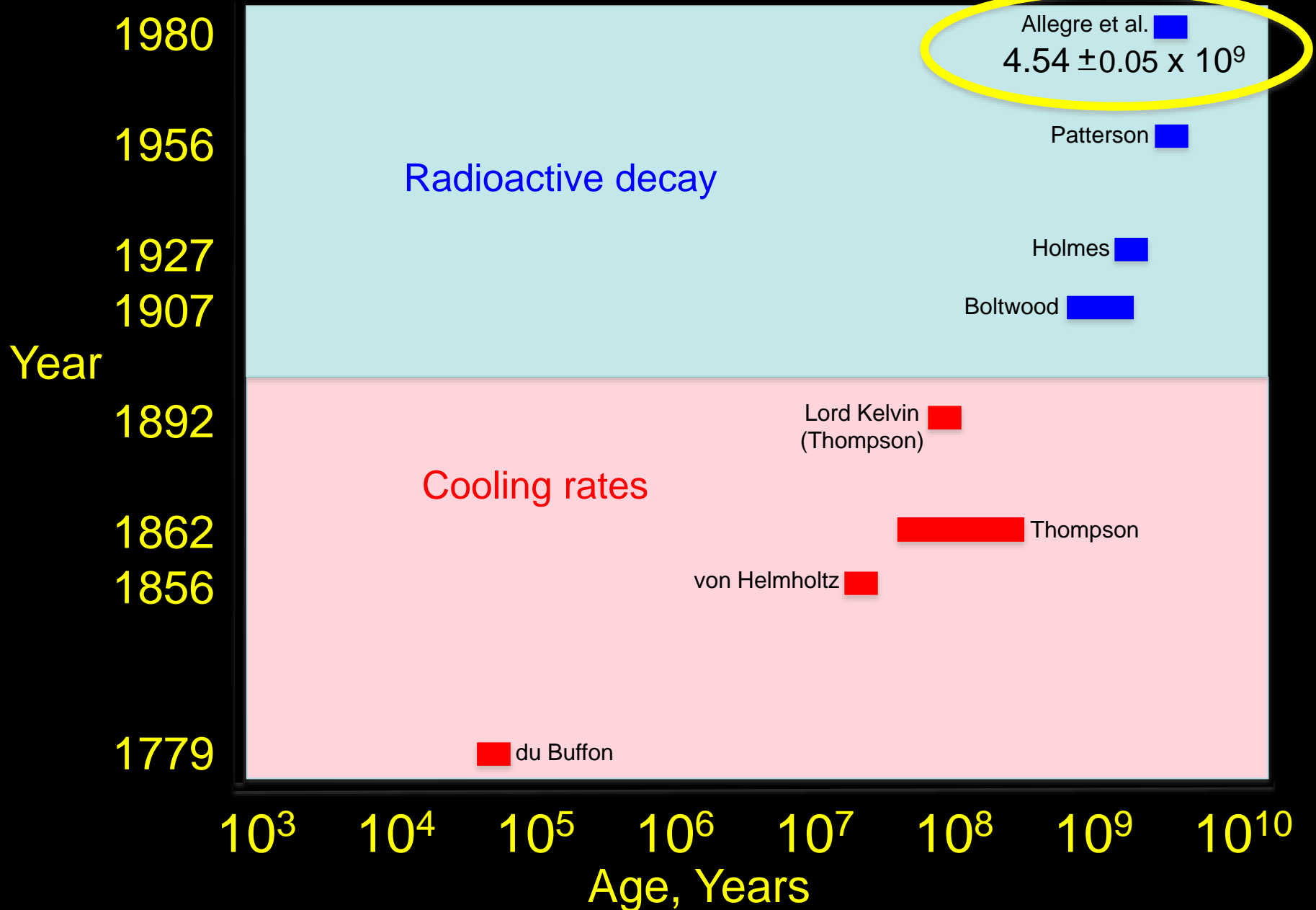
Hydrosphere

Interior





# Determination of Earth's Age vs Year of Calculation



# The earliest forests

385 to 252 million years ago







**Ancient rocks record evidence of changing planetary environments & biological evolution**

Toroweap overlook, Grand Canyon, AZ - oldest rocks ~500 million years

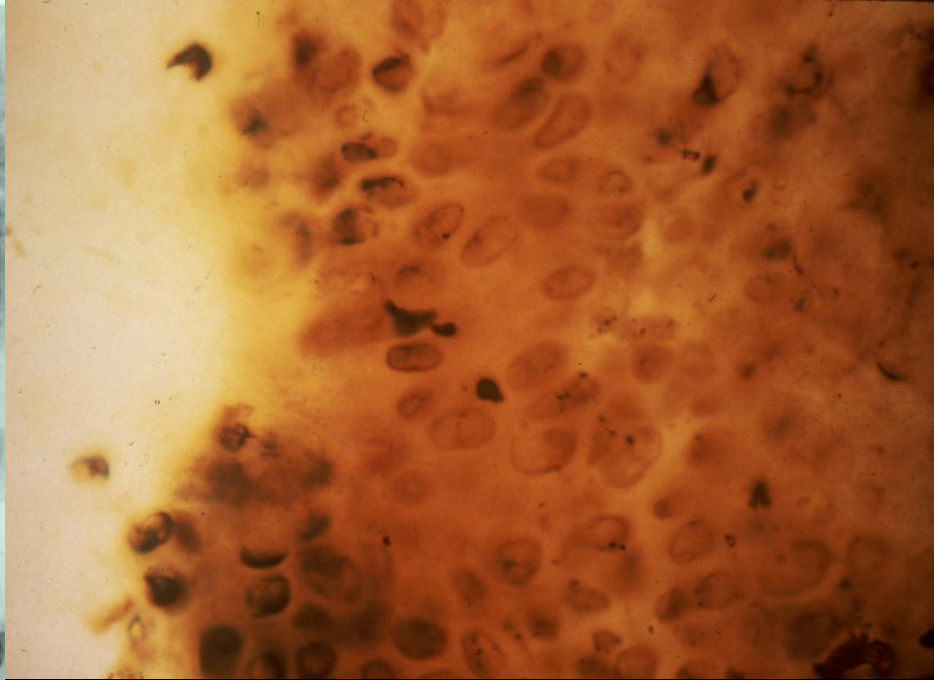
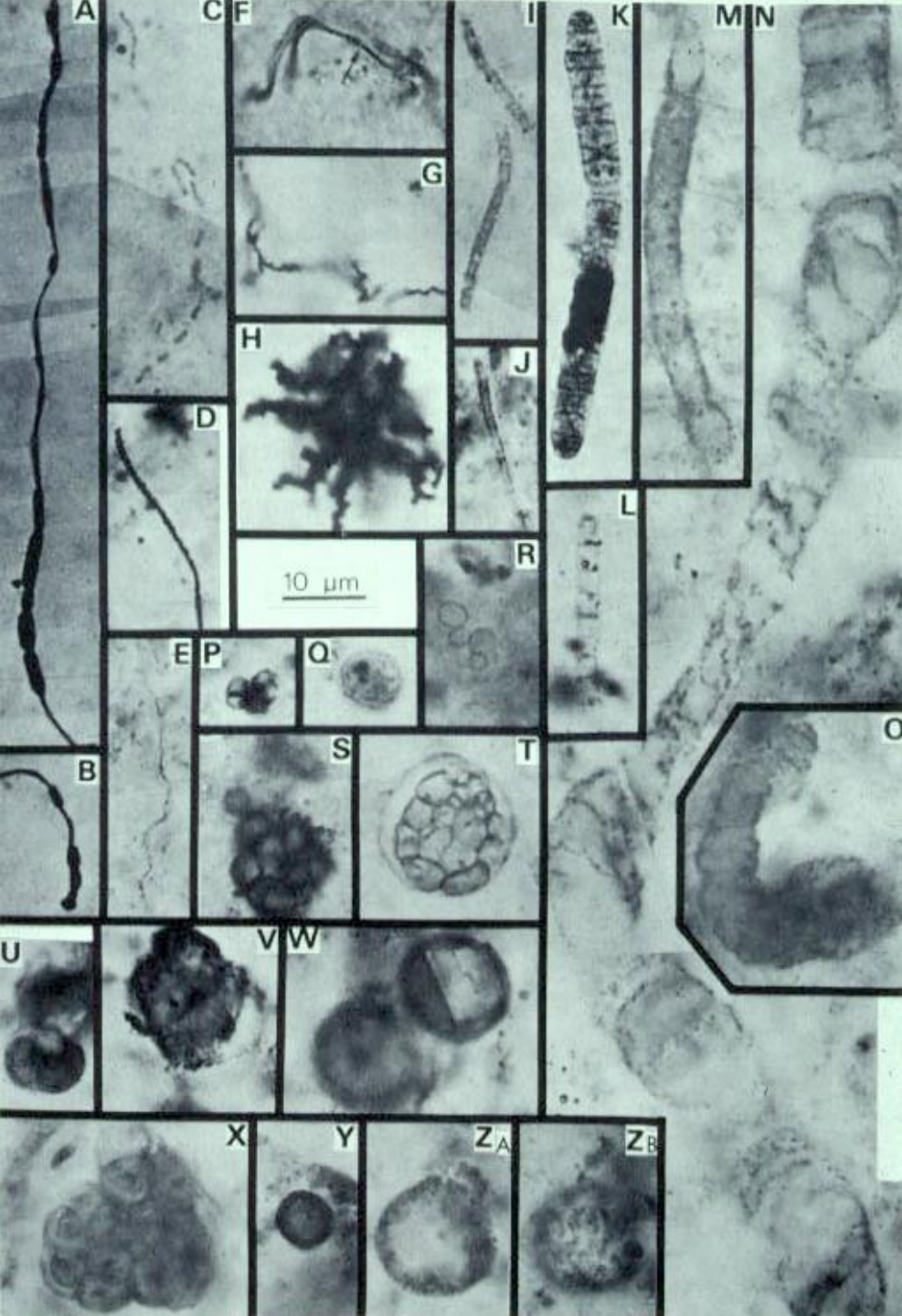




**Darwin's Dilemma.** Charles Darwin's book, *On the Origin of Species*, first focused attention on the missing Precambrian fossil record and the problem it posed to his theory of evolution:

“There is another . . . difficulty, which is much more serious. I allude to the manner in which species belonging to several of the main divisions of the animal kingdom suddenly appear in the lowest known [Cambrian-age] fossiliferous rocks . . . If the theory be true, it is indisputable that before the lowest Cambrian stratum was deposited, long periods elapsed . . . and that during these vast periods, the world swarmed with living creatures . . . [But] to the question why we do not find rich fossiliferous deposits belonging to these assumed earliest periods before the Cambrian system, I can give no satisfactory answer. The case at present must remain inexplicable; and may be truly urged as a valid argument against the views here entertained...”







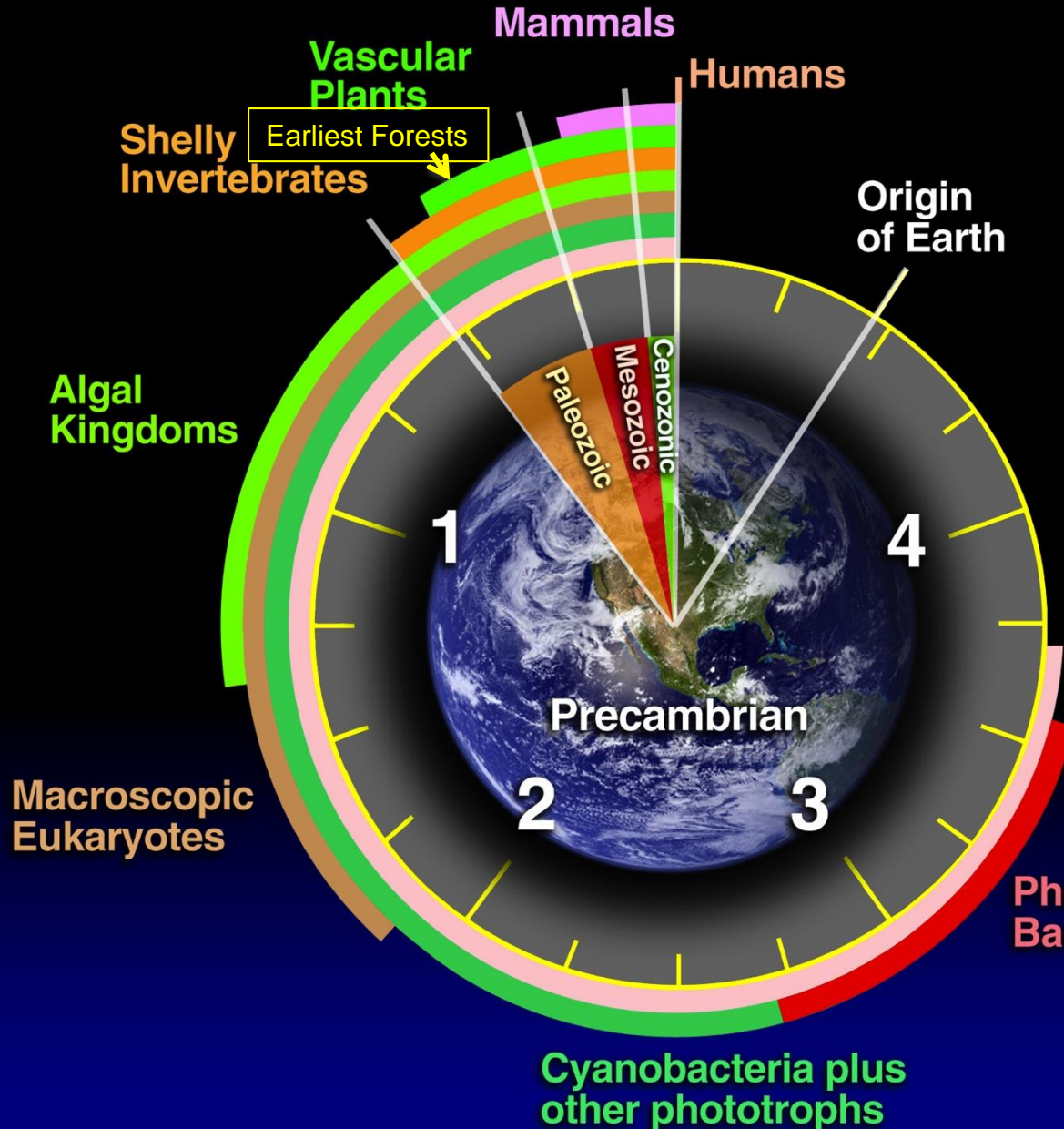
# Earth's Biogeologic Clock

Billions of Years Ago

Life

Phototrophic Bacteria

Cyanobacteria plus other phototrophs

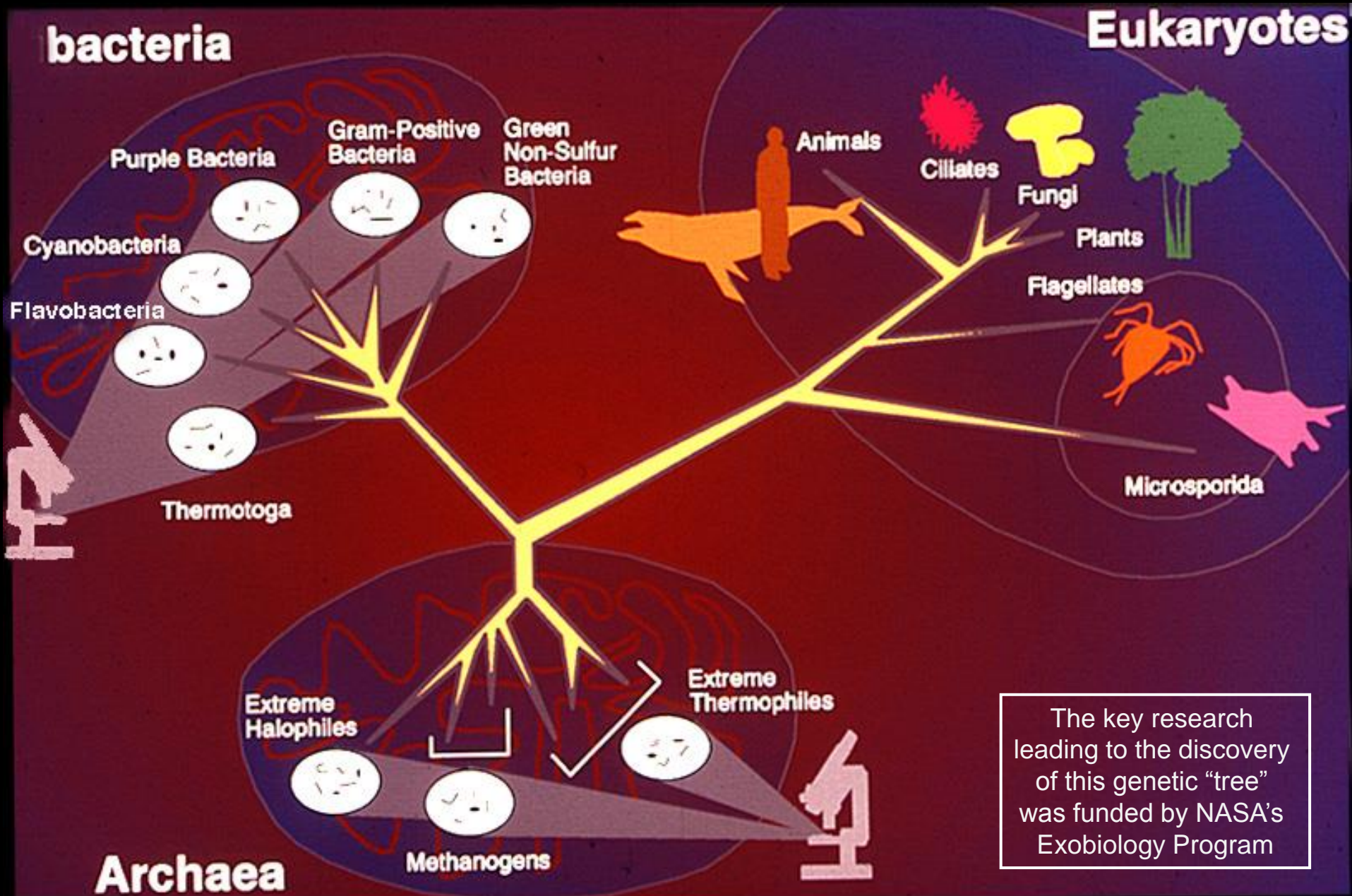


David Des Marais, Ames Research Center, NASA  
Cheryse Triano, TopSpin Design Works

Plants & animals are MUCH younger than the earliest life. Our biosphere consisted ONLY of single-celled organisms for more than 80 percent of its known history.



# "Tree of Life" - genetic relationships derived from ribosomal RNA





## Bumpass Hell



**Volcanic Fumaroles & Hot Springs**  
Water, nutrients and energy for life; key habitat in early biosphere



# Lassen Volcanic National Park



Lassen's Volcanism, volcanic rocks and water provide information about habitable environments and microbial communities relevant to early Earth.



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# Four Approaches To Understanding the Origins of Life

ORIGINS OF SOLAR SYSTEMS,  
PLANETS AND ENVIRONMENTS  
REQUIRED FOR LIFE

LIVING BIOCHEMICAL  
RECORDS OF EARLY LIFE

CHEMICAL EVOLUTION

ORIGINS  
OF  
LIFE

BIOLOGICAL EVOLUTION

CHEMICAL SPECIES AND  
MECHANISMS LEADING  
TO THE ORIGINS OF LIFE

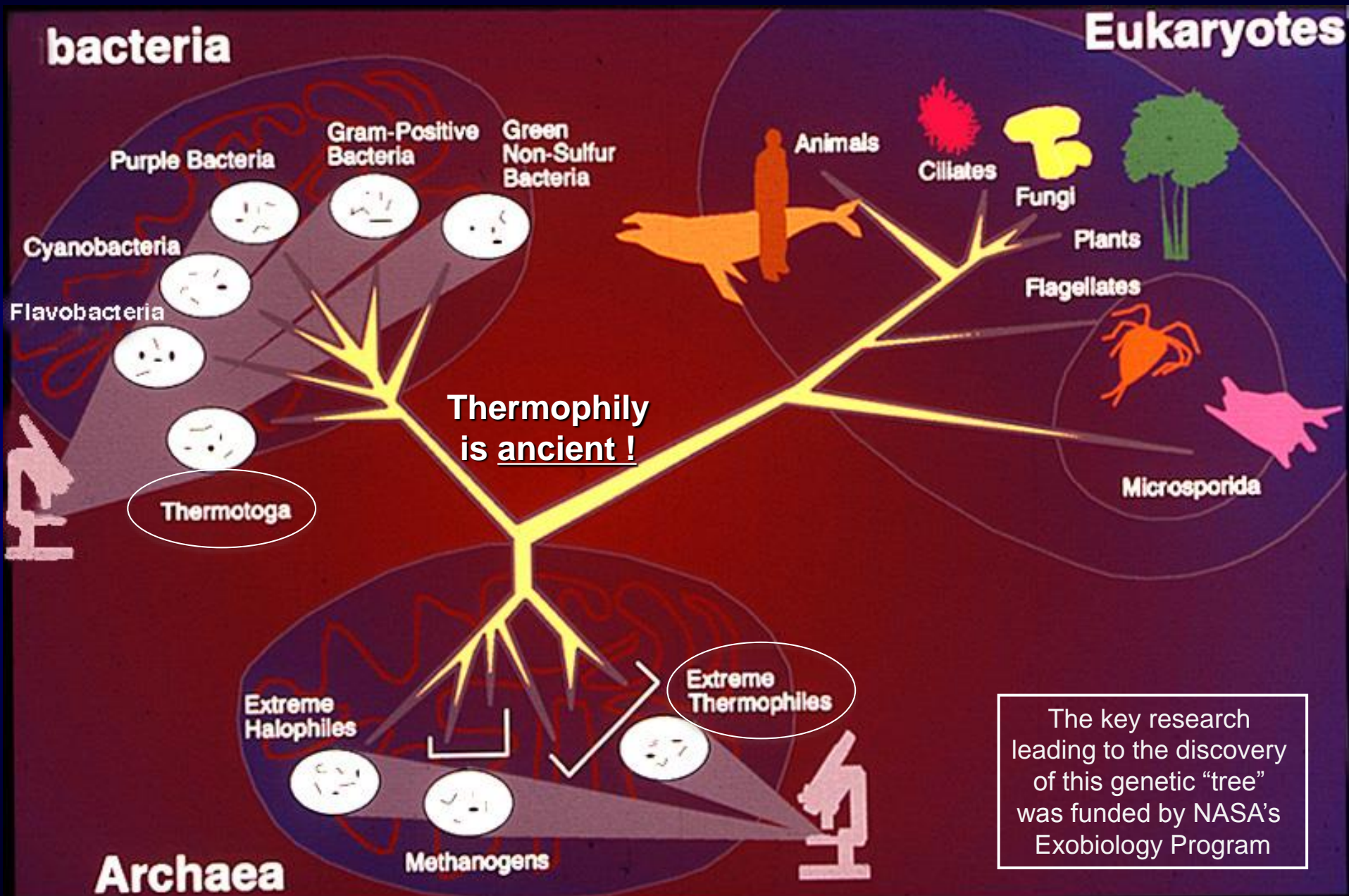
GEOLOGICAL RECORDS  
OF EARLY BIOSPHERES

PAST

TIME

PRESENT

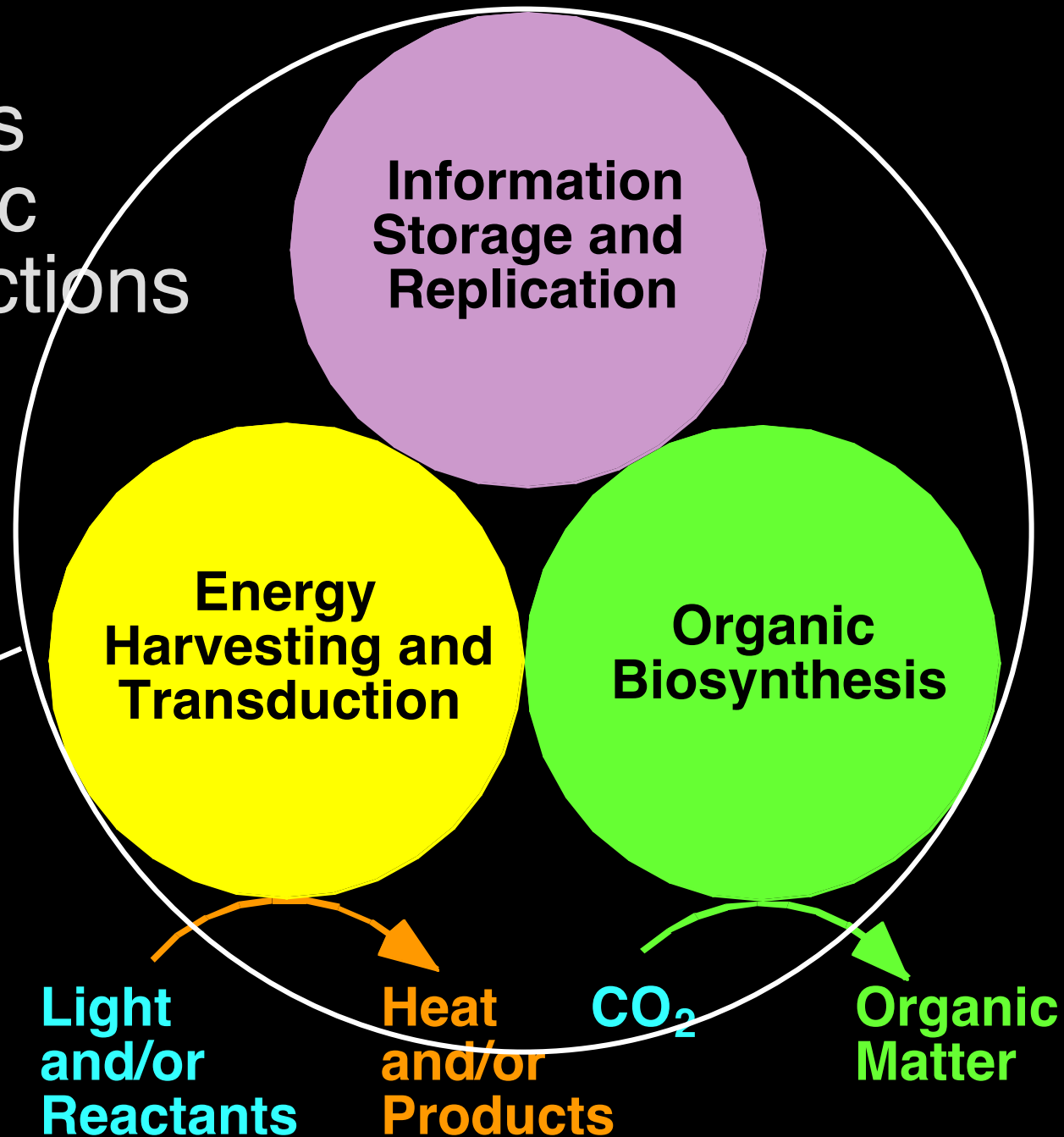
# "Tree of Life" - genetic relationships derived from ribosomal RNA





# Life's Basic Functions

Darwinian  
evolution





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beyond Earth**

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# Probability of Life in the Universe

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$$B = R^* f_p n_e f_l L \quad \text{where:}$$

**B = Number of biospheres**

**$R^*$  = Formation rate of stars suitable for life**

**$f_p$  = Fraction of those stars with planetary systems**

**$n_e$  = No. of planets per solar system suitable for life**

**$f_l$  = Fraction of  $n_e$  where life actually appears**

**L = Lifetime of biospheres**



# Exoplanet Discoveries

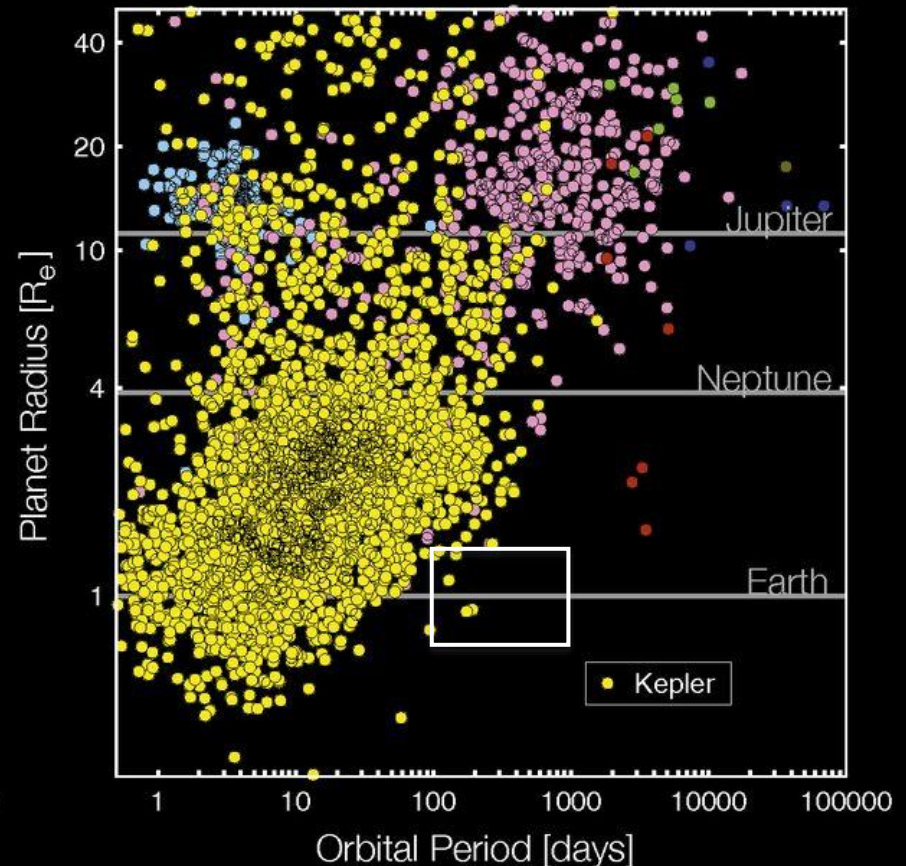
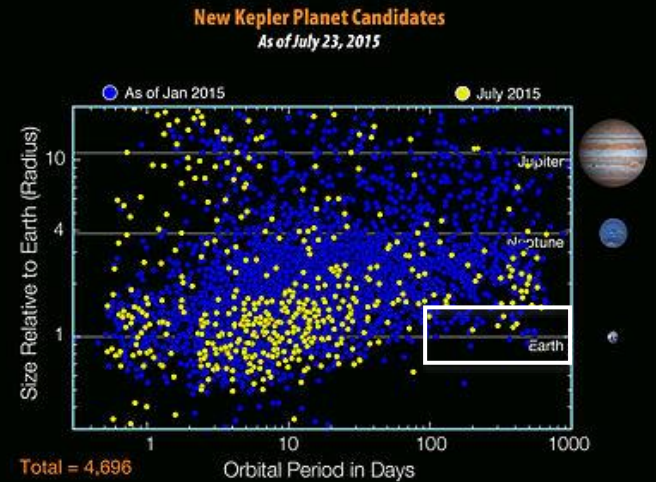
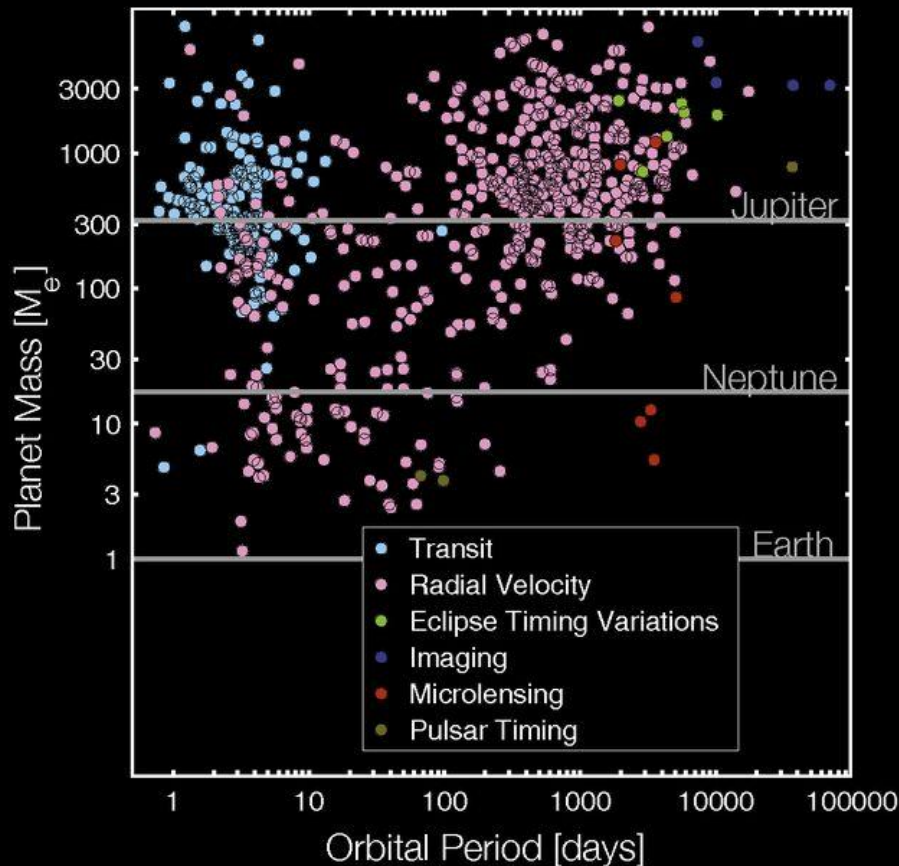
Orbital Period [days]

vs

Planet Radius [Earth masses]

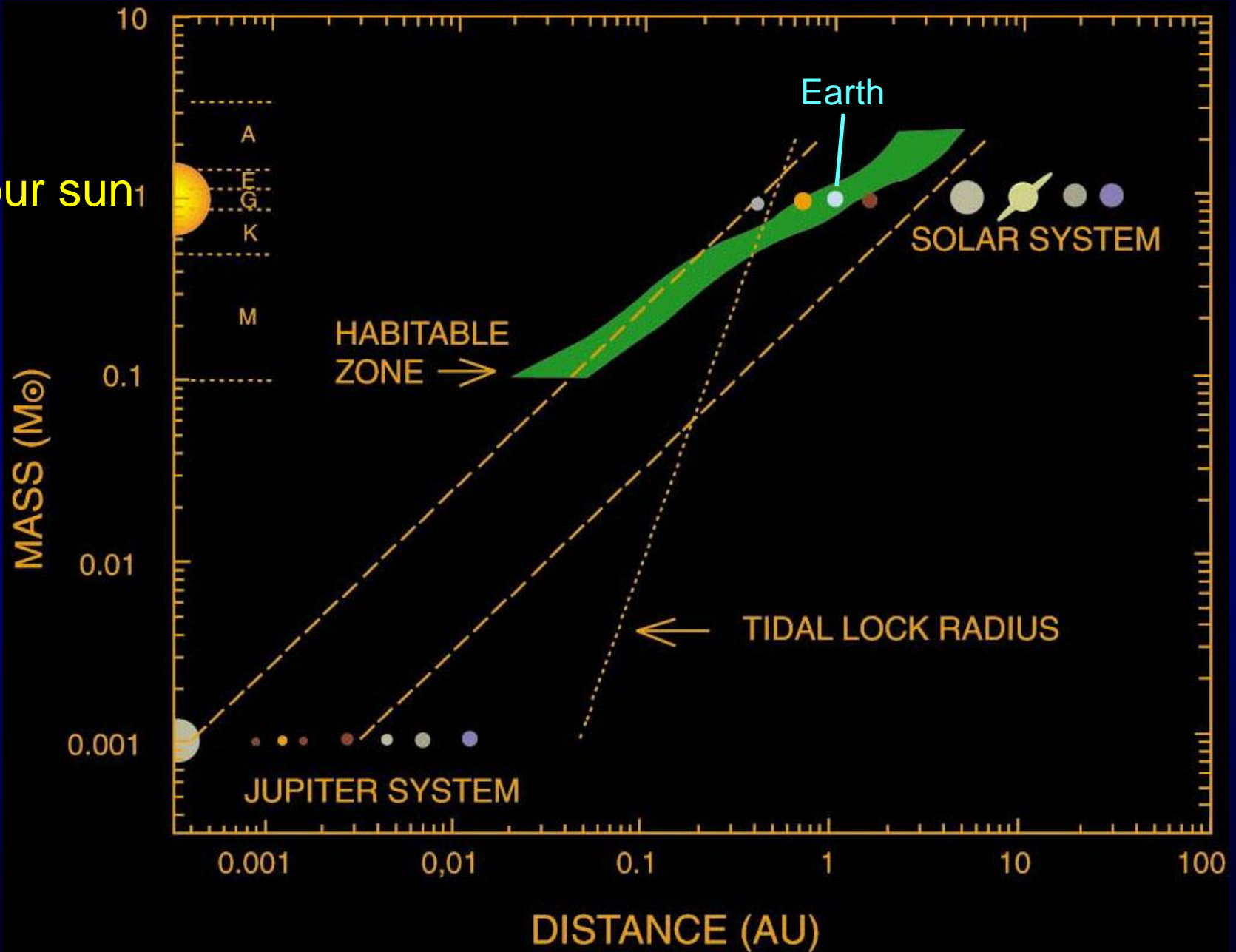
(July 2015)

(Batalha, Jan. 2014)

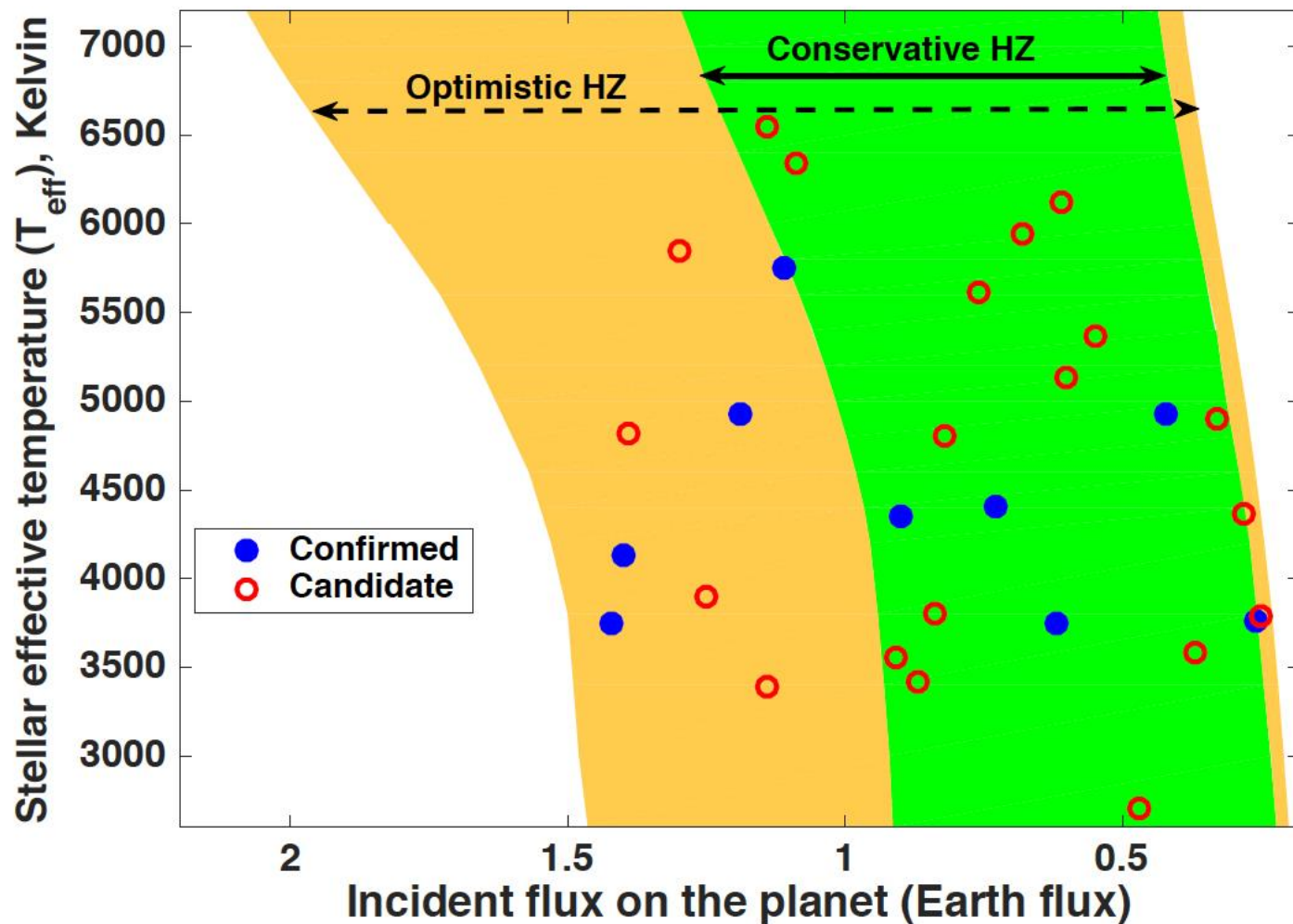


# Circumstellar Habitable Zones - Planet Orbit Radius vs Mass of Star

our sun







**Figure 1.** The stellar effective temperature as a function of incident flux for the unconfirmed candidates (open red circles) and confirmed planets (solid blue circles) from Table 2. These are overplotted on the conservative and optimistic HZ.

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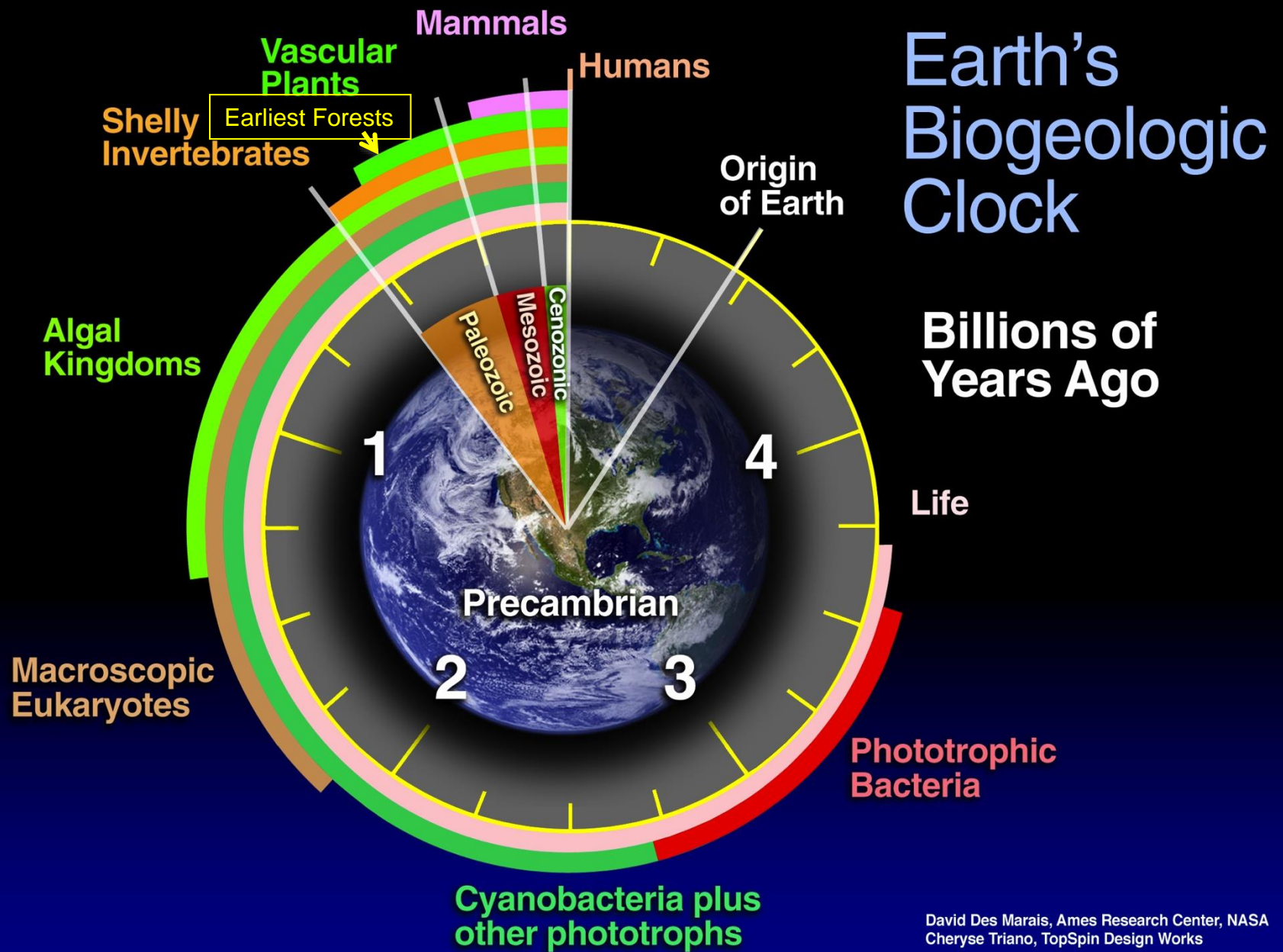
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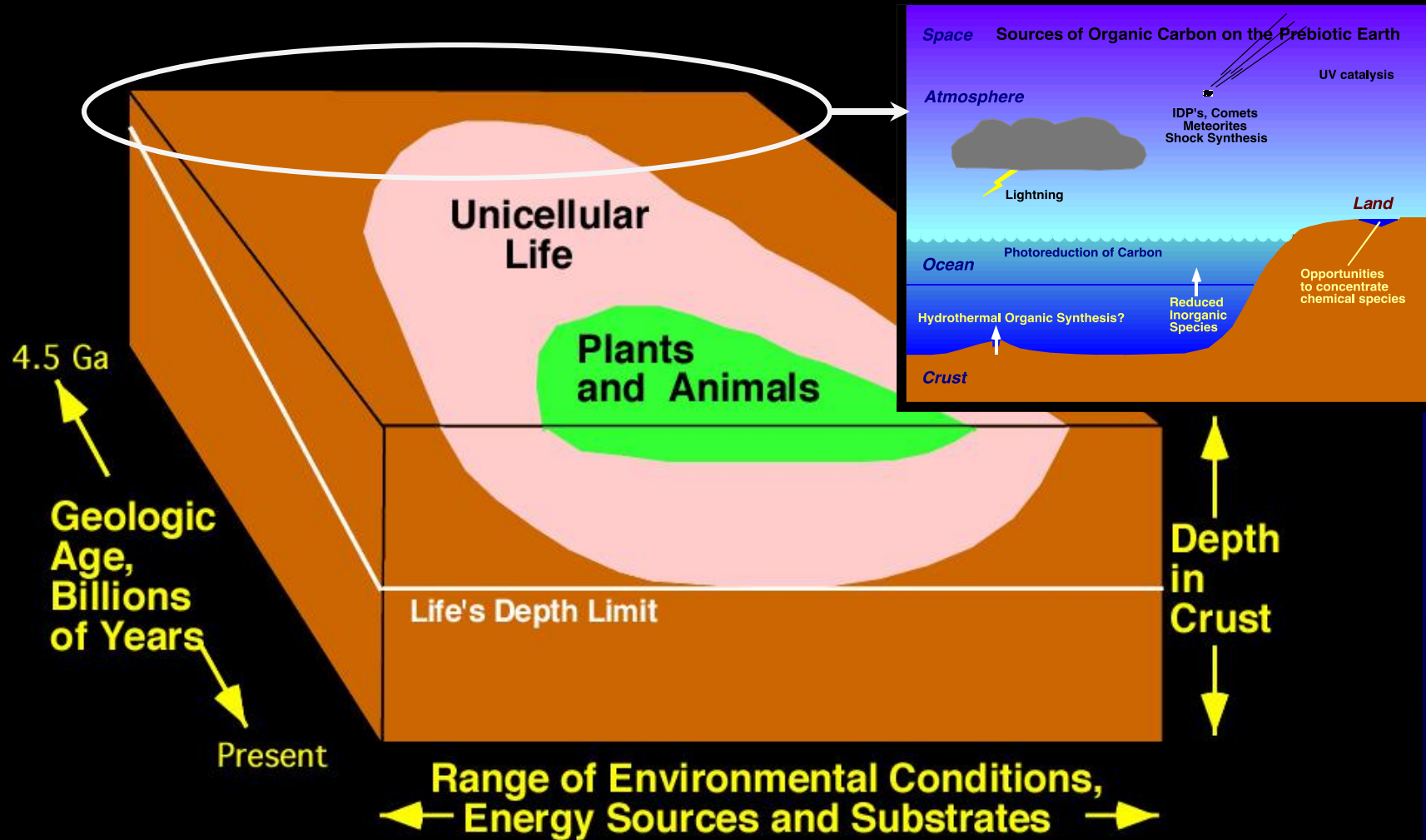




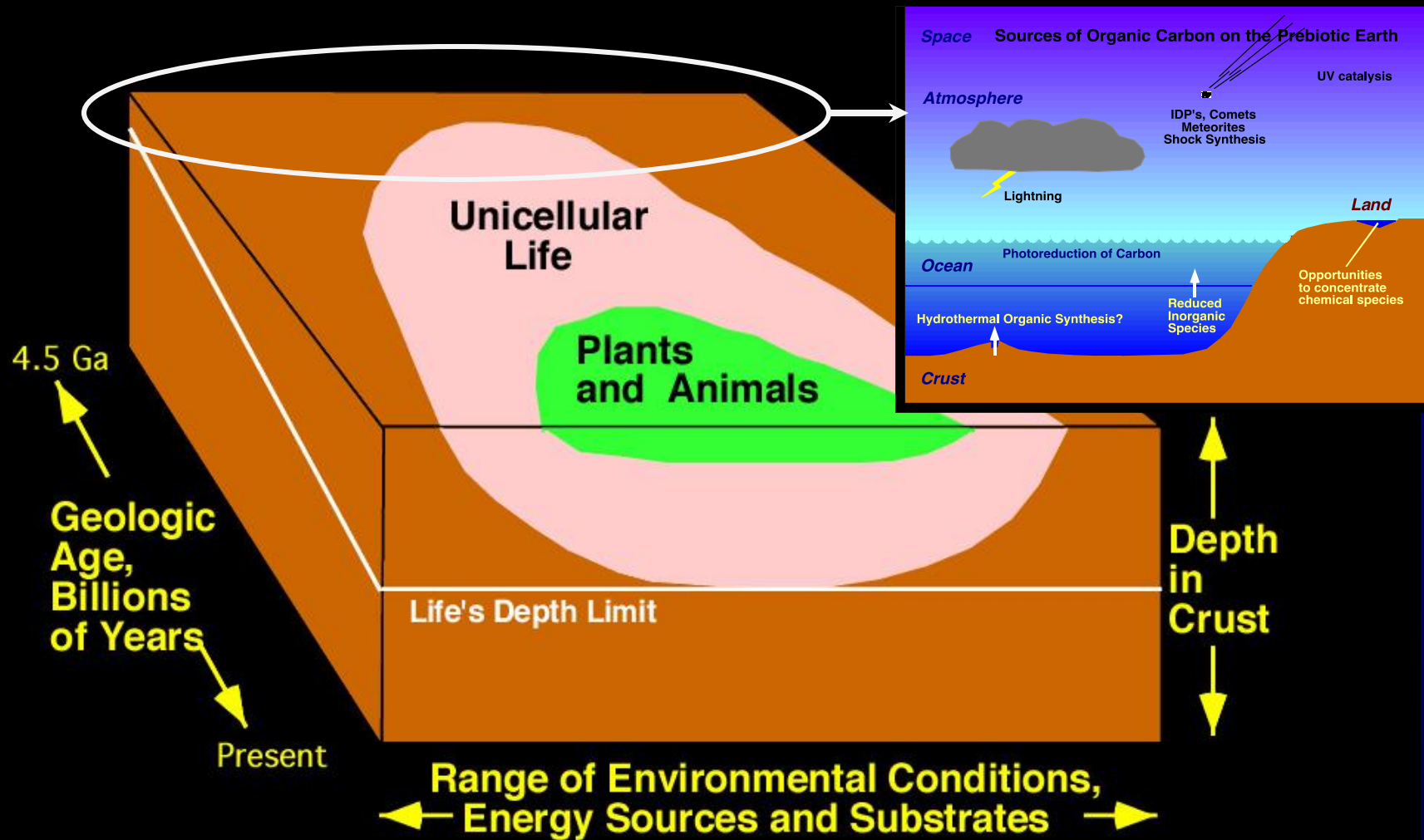
David Des Marais, Ames Research Center, NASA  
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The ages of the oldest known fossils are limited by the quality of preservation of the oldest rocks that could have contained those fossils

Knowledge of early planetary environments is critical to understanding origins & early evolution of life







But Earth's earliest records have been largely obliterated.  
Mars' earliest record is probably still well-preserved!